

VACUUM INSULATOR FLASHOVER MEASUREMENTS FOR MICROSECOND PULSES

J.R. Boller, P.J. Goodrich,* J.D. Shipman, Jr.,**
S.J. Stephanakis, and R.J. Commisso

Pulsed Power Physics Branch, Plasma Physics Division
Naval Research Laboratory, Washington, DC 20375

Abstract

The flashover characteristics of the water/vacuum insulator assembly of the Gamble II pulsed power generator at the Naval Research Laboratory (NRL) were investigated to determine the insulator's applicability for use with the recently assembled Hawk generator, which features inductive store/plasma opening switch (POS) technology. Hawk produces a 1- μ s voltage pulse with a peak value of 265 kV at the vacuum insulator during the POS conduction time. When the POS opens, a voltage pulse as high as 1.5 MV can be produced at the switch. The Gamble insulator was originally designed for \sim 2 MV, 75 ns voltage pulses. Gamble II was re-configured for a long-pulse mode to produce a 1 MV, 1.5 μ s wide output pulse for these tests. Flashover data will be presented for voltage pulses of 556 to 843 kV with the time from the beginning of the pulse to flashover ranging from 0.8 to 2.25 μ s. It was found that the results did not follow the familiar $t^{-1/6}$ relationship for flashover. Nevertheless, the performance was more than adequate for this application and an identical insulator has been used successfully on Hawk for nearly a year.

Introduction

The insulator assembly that serves as the interface between water and vacuum on the Gamble I [1] and Gamble II [2] pulsed power generators at the Naval Research Laboratory (NRL) was designed to withstand 2-MV peak voltage pulses of 70-80 ns duration. This diaphragm-type, non-segmented insulator has been denoted as the "G5" diode insulator. With the emergence of generators featuring inductive store/plasma opening switch (POS) technology [3], a study was undertaken to determine if the same relatively simple and inexpensive insulator design could be utilized with the much longer but lower level voltage pulses associated with such generators. In particular, it was desired to use the existing insulator assembly from the de-commissioned Gamble I generator on the new Hawk [4,5] generator recently assembled at NRL. In this application the insulator would have to withstand a 1- μ s voltage pulse with a peak value of 265 kV during the POS conduction time, plus a much larger (\sim 1.5 MV) but shorter (60-80 ns) pulse at the time of switch opening. Gamble II was modified to test the G5 insulator for the long-duration, lower-level portion of the Hawk pulse.

Gamble II Experimental Configuration

The Gamble II generator, shown in Fig. 1, was modified for the insulator test by short-circuiting the intermediate store switch and the output oil switch to produce a MV-level, μ s-duration output pulse. Circuit modeling of this configuration predicted that an open circuit output voltage of \sim 1 MV with a full width at half maximum of 1.5 μ s could be produced at a very modest Marx charging voltage. The modeling also indicated that the shape of the output pulse could be improved if the short circuit across the oil switch had an inductance of 1 μ H. This was accomplished by installing a multi-turn coil between the switch electrodes.

A schematic of the G5 diode assembly is shown in Fig. 2. The vacuum gap between the negative center conductor hub and the grounded outer conductor was 6.5 cm and the radial length between the center conduc-

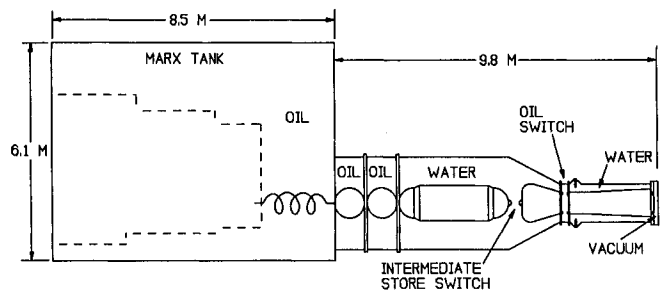


Fig. 1. Schematic Layout of the Gamble II Generator

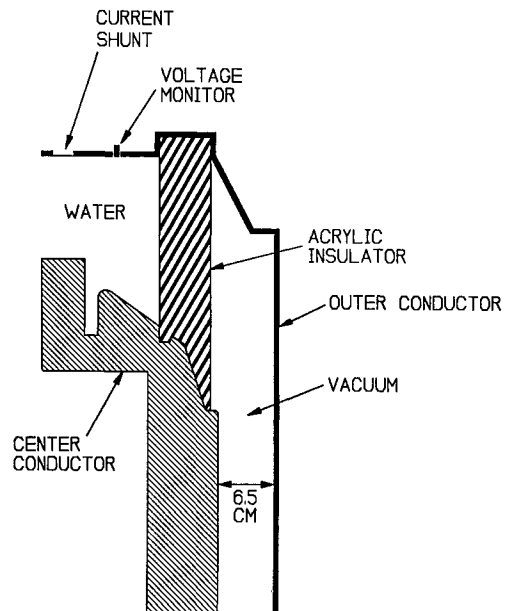


Fig. 2. Diagram of the NRL G5 Diode Assembly

tor and outer conductor along the acrylic interface was 30 cm. The insulator voltage was measured by a capacitive voltmeter located 5 cm upstream (toward the Marx) of the insulator and current was measured by a resistive shunt located 10 cm upstream of the insulator. Insulator flashover was evident by a sudden drop in the voltmeter signal and an abrupt rise in current, both resulting from the low impedance, low inductance short. The generator peak output voltage was adjusted by varying the Marx charge voltage.

Experimental Results

Nine shots were fired with an open circuit load where the insulator flashed because the electric field parallel to the insulator surface, E_s , was exceeded for the effective times involved. The voltages and currents for two of these shots at different peak output voltage levels are shown in Fig. 3. Flashover is evident from the rapid changes in these waveforms and also

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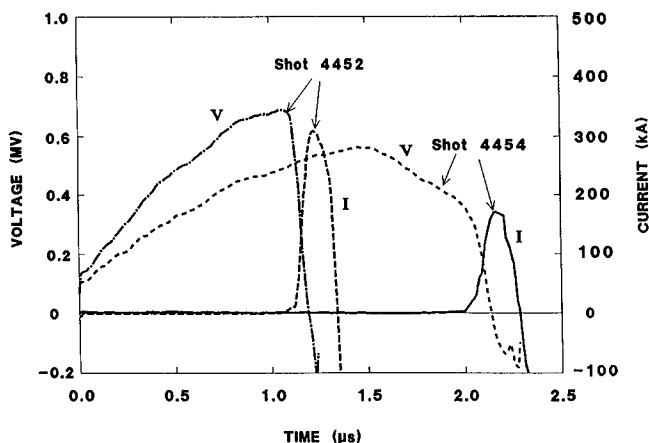


Fig. 3. Typical Waveforms for Two of the Open Circuit, Long Pulse Shots on Gamble II

from the observation of surface tracking on the insulator after each shot. Shot 4452 is a higher-level shot where the insulator flashed while the voltage was still rising. This contrasts Shot 4454, where the the lower-level voltage had passed the peak and was dropping when flashover occurred. Although these shots were nominally open circuit, it is possible that, with the peak voltages ranging from 556 to 843 kV, the electric field on the enhanced edge of the cathode center conductor exceeded the threshold for electron emission. Ultra-violet light from these emission sites, or from where these emitted electrons struck the outer conductor, may have triggered the flashovers.

During these tests insulator flashover occurred over a range of 0.8 to 2.25 μ s from the beginning of the pulse, with a corresponding t_{eff} (time that the voltage exceeded 89% of the maximum value) of 0.17 to 0.55 μ s. The results of all the open circuit shots are shown as crosses in Fig. 4 where the mean flashover field is plotted as a function of t_{eff} . In addition to the open circuit shots, a number of shots were taken with a 12-cm dia. hollow cathode protruding from the central hub. This was meant to test the effect on insulator flashover of passing a small current in an electron beam, that is a direct line-of-sight to the insulator. Most of these shots drew so much current that the voltage was too low to cause flashover, however flashover did occur on two shots that had a large anode-cathode gap. These points are shown in Fig. 4 as triangles. They are significantly lower than the shots without

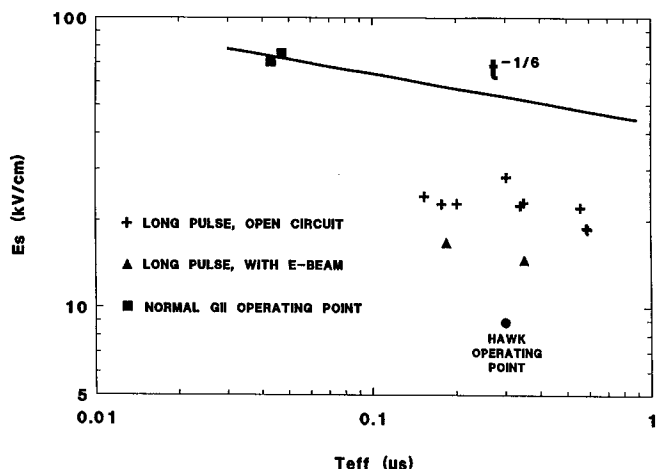


Fig. 4. Flashover Field vs. T_{eff} for the G5 Insulator

current flow, indicating the presence of the e-beam current decreased the insulator flashover voltage. This is probably a result of e-beam generated ultra-violet light interacting with the insulator surface.

Also shown in the figure are two points corresponding to the standard Gamble II pulse (2.1 MV, $t_{eff} = 45$ ns) with a line drawn through these points representing the familiar $t_{eff}^{-1/6}$ relationship [6] of vacuum insulator flashover for short pulses. Figure 4 shows that the flashover levels of the open circuit, long pulse shots were considerably less than what would be predicted by the $t_{eff}^{-1/6}$ relation. Although the flashover voltages for the long pulses were not as high as might have been expected, they were significantly higher than the Hawk operating point during POS conduction, which is shown as a filled-in circle in Fig. 4.

Insulator Performance on Hawk

Based on the above results, the decision was made to install the G5 insulator assembly on the Hawk generator where it has been used successfully for more than a year. In addition to the normal lower level pulse, high level, short duration pulses of more than 1.5 MV have been produced across the insulator during the opening phase of the POS.[5] The insulator voltage for a typical high-voltage shot is shown in Fig. 5 where the low level voltage (100-200 kV for the Hawk charging voltage of 80 kV) during POS conduction had a duration of 0.7 μ s after which the POS opened, producing a voltage at the insulator of about 1.6 MV with a FWHM of 70 ns without flashover. Occasionally, flashovers of the insulator occurred, but after the required power pulse was delivered to the load. Also, no servicing of the insulator is required after a shot with flashover to restore full voltage operation.

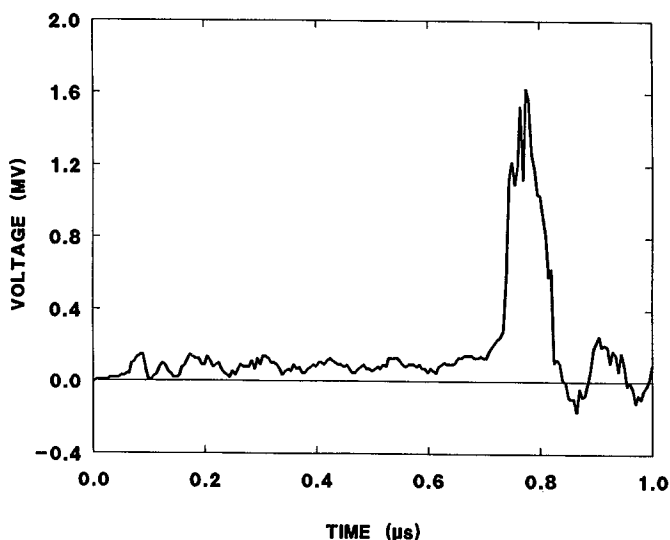


Fig. 5. Typical Hawk Insulator Voltage Waveform

Summary

The Gamble II test results clearly showed the long pulse requirements of Hawk (265 kV, $t_{eff}=0.3$ μ s) could be easily met with the G5 insulator, because flashovers only occurred for voltages greater than 675 kV for pulses with this value of t_{eff} . However, the Gamble II tests did not simulate the complete time history of the Hawk voltage. In particular, the voltage spike associated with POS opening was not simulated. Thus, these tests could not provide conclusive proof that the insulator would be adequate for Hawk. On the other hand,

if the insulator had failed these tests then it would have been certain that it would not be suitable for the Hawk generator.

The G5 insulator has been successfully fielded on the Hawk generator where it has been in operation for over a year. In the few cases that flashovers have been observed, they have occurred after the required power pulse has been delivered to the load.

References

- [1] G. Cooperstein, J.J. Condon, and J.R. Boller, Journal of Vacuum Science and Technology, 10, 961 (1973).
- [2] J.R. Boller, J.K. Burton, and J.D. Shipman, Jr., 2nd IEEE International Pulsed Power Conf., (Lubbock, TX, 1979), p. 205.
- [3] G. Cooperstein and P.F. Ottinger, Guest Editorial, IEEE Trans. Plasma Science, PS-15 (Dec. 1987).
- [4] J.R. Boller, R.J. Commisso, P.J. Goodrich, D.D. Hinshelwood, J.C. Kellogg, J.D. Shipman, Jr., B.V. Weber, and F.C. Young, NRL Memorandum Report 6748, January 1991.
- [5] P.J. Goodrich, J.R. Boller, R.J. Commisso, D.D. Hinshelwood, J.C. Kellogg, and B.V. Weber, this conference.
- [6] J.C. Martin, AWRE Internal Report No. SSWA/JCM/713/157 (1971).

*Jaycor, Inc., Vienna, VA 22180-2270

**Sachs/Freeman Associates, Landover, MD 20785